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(54) IMPROVEMENTS IN OR RELATING TO DESALINATION PLANT

(71) I, JOHN ALAN CHARLES KENTFIELD, a British subject, of 7, Mortimer Lodge, Albert Drive, Wimbledon, London, S.W.19, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a desalination plant.

Certain previously proposed desalination plants have been constructed to produce outputs of fresh water and of electricity. Such dual-purpose plant is only desirable where a market exists for the electricity generated and would not be desirable, for example, where large quantities of desalinated water are required for irrigation purposes in sparsely populated areas. Previous proposals for single-purpose desalination plant in which the sole output is desalinated water in general comprise a multi-stage flash evaporator which is capable of using only low-pressure steam.

According to the present invention there is provided a desalination plant comprising first apparatus for producing desalinated water the operation of which produces shaft power and second apparatus for producing desalinated water which depends essentially for operation on a thermal input derived from the exhaust of the first apparatus, said first and said second apparatus having intakes for saline water arranged in parallel.

Further according to the present invention there is provided a desalination plant comprising a first apparatus operable with high-pressure steam to produce an output of desalinated water and low-pressure steam and a second apparatus operable by the exhaust of the first apparatus to produce an output of desalinated water, said first and said second apparatus having saline water intakes arranged in parallel.

Still further according to the present invention there is provided a desalination plant comprising a vapour compression evaporator, a turbine-driven compressor arranged to provide heating fluid to the vapour compression evaporator and a multi-stage flash evaporator connected to receive exhaust steam from the turbine, respective inlets to the vapour compression evaporator and to the multi-stage flash evaporator being arranged for parallel connection with respect to a saline water source.

Yet further according to the present invention there is provided a desalination plant comprising a vapour compression evaporator having an outlet connected to a compressor, a heat-exchanger the cold pass of which receives heat from the hot pass thereof, a heater downstream of the cold pass and communicating at its outlet and with the inlet of a turbine, an outlet of the turbine connected to the hot pass of the said heat-exchanger, a de-superheater connected to receive the output of the said hot pass of the heat-exchanger, heating pipes arranged within a multi-stage flash evaporator and connected to receive steam from the de-superheater, said vapour compression evaporator being connected to deliver steam to the inlet of the said compressor and having heating means therein connected to receive steam from the de-superheater, and a further heat-exchanger having a hot pass for brine delivered from the vapour compression evaporator and a second hot pass connected to receive desalinated water from the vapour compression evaporator, said further heat-exchanger having a cold pass through which salt water can be delivered to the vapour compression evaporator after taking up heat in said further heat-exchanger, said multi-stage flash evaporator having an inlet for salt water arranged in parallel with an inlet to said cold pass of the further heat-exchanger.

Certain embodiments of desalination plant in accordance with the invention, will now be

described, by way of example, with reference to the accompanying diagrammatic drawings, in which:

Figure 1 is a graph in which enthalpy is plotted against entropy for a plant in accordance with the invention;

Figure 2 is a graph in which absolute temperature is plotted against entropy for a plant in accordance with the invention;

Figure 3 is a circuit diagram of a first embodiment of a plant in accordance with the invention; and

Figure 4 is a diagram of a second embodiment.

In desalination plant in accordance with the invention the division of the total output of the turbine between shaft power output and thermal-output is shown in the enthalpy (h) versus entropy (S) and temperature (T) versus entropy (S) diagrams shown in Figures 1 and 2 respectively. These diagrams are applicable to the embodiment shown in Figure 3. The encircled numerals refer to state points bearing these numerals shown in the circuit diagram in Figure 3.

Figure 3 illustrates the first embodiment in which a steam turbine 20 is connected to receive high-pressure steam from a boiler (not shown) and is coupled to a compressor 21 by a shaft 22. Exhaust steam passes from the turbine 20 through a duct 23 into a multi-stage flash evaporator 24 where the steam serves as the heat input and is condensed therein. A pump 25 serves to return the condensate from the evaporator to the boiler. The evaporator 24 receives an intake of sea (or other saline) water through an intake 26, including a pump 27 and the fresh water produced in the evaporator is delivered through an outlet 28.

The compressor 21 forms part of the circuit which acts as a vapour compression still and this circuit will now be described. A sea water intake 30, arranged in parallel with the intake 26, leads to a pump 31 which delivers its output through a duct 32 to the cold pass 33 of a heat-exchanger acting as a feed heater 34. The hot pass 35 forms part of the delivery for de-salinated water and its connections will be further described hereinafter. The outlet 36 from the cold pass 33 communicates with an evaporator 37 through a duct 38 and the steam driven off from the bulk of liquid 39 passes through a duct 40 to the inlet 41 of the compressor 21. The steam is compressed and leaves the compressor through a duct 42, from which it is delivered to heating pipes 43 of the evaporator 37. Heat is given up to the brine and the steam in the pipes 43 condenses and the condensate is fed to the hot pass 35 of the feed heater 34 where further heat is given up to the incoming sea water and is finally delivered through an outlet 44.

It will be appreciated that the pre-heating stage for the sea water provided by the feed heater 34 can be omitted or alternatively run in parallel with a heat-exchanger 50 in which the cold pass 51 thereof receives heat from concentrated brine rejected through an outlet 52 from the evaporator 37. In a further or alternative modification account is taken of the requirements for a compressor that the steam should be dry if erosion/corrosion problems are to be at least mitigated. In this modification a heat-exchanger 53 is provided upstream of the inlet 41 of the compressor 21 in order to convert the wet steam derived from the evaporator 37 into dry steam. The heat requirement for this drying operation is derived from a by-pass duct 54 which leads to the hot pass 55 of the additional heat-exchanger, the cooled steam derived from the hot pass 55 being returned to the main duct 42 leading from the outlet of the compressor to the heating coil 43 of the evaporator 37.

The following table presents the physical data for each of the state points, indicated by ringed numerals, shown in Figures 1 to 3:

State Point	Pressure (Lb/In²Abs)	Temp. (°F.)	Enthalpy (BTU/Lb)	M/M Boiler	Phase
1	2000	1090	1530	1	S.H.S. (Superheated Steam)
2	35	290	1185	1	S.H.S.
3	35	259.3	227.9	1	Liquid
4	14.7	T_{IN}	—	17.3	Liquid
5	14.7	212	180.1	17.3	Liquid
6	14.7	212	1150.4	17.3	D.S.S. (Dry Saturated Steam)
7	18.0	255	1170.4	17.3	S.H.S.
8	18.0	222.4	190.6	17.3	Liquid
9	$14.7 \leqslant P_9 \leqslant 18.0$	T_{IN} + 10°F.	—	17.3	Liquid
10	14.7	—	—	12.0	Liquid

In the table M/M BOILER is defined as <u>mass flow of fluid at numbered point</u> mass flow of steam supplied to desalination plant from the boiler.

In an analysis of a combined-process plant as illustrated in Figure 3 with a steam input from a boiler for driving the turbine at a pressure of 2,000 lb. per square inch absolute, it has been calculated that approximately 29 lb. of desalinated water per pound of steam from the boiler can be produced. The evaporator in the vapour compression still of the plant was selected to operate at atmospheric pressure to simplify construction of the still.

A study of the effects of the performance of the combined-process desalination plant of boiler steam pressure and temperature shows that the product mass flow as a fraction of boiler steam mass flow increases with boiler pressure. Further, the heat input required to produce a given quantity of product mass flow decreases as the boiler pressure increases.

An approximate economic analysis of a combined-process plant similar to that shown in Figure 3 showed that desalinated water production plants in a combined-process plant are approximately 60% of the corresponding costs in existing and proposed dual purpose or single purpose plant in which multi-stage flash evaporators are incorporated.

It was concluded in a feasibility study of using a large desalination plant to irrigate land, that a desalination plant in accordance with this invention comparable in cost with an orthodox 1,000 mw. coal-fired electricity generating station would probably be capable of supplying an area of 825 square miles with a supply of desalinated water equivalent to 15 inches of rain each year.

Referring now to the second embodiment illustrated in Figure 4, although certain of the parts illustrated in Figure 3 are common with those of Figure 4, it will be more convenient to describe the parts separately. Sea water or other saline water is drawn in to a multi-stage flash evaporator 70 through an inlet 71 and concentrated brine is delivered through the outlet 72 whilst desalinated water is delivered through an outlet 73. Heat input to the multi-stage flash evaporator 70 is derived from heating pipes 74 and the heat supply for these pipes will become apparent from the description which is given hereinafter.

The vapour compression evaporator 75 has an inlet 76 for sea water which has been preheated in a heat-exchanger 77 having a cold pass 78 and two hot-passes 79, 80. The hot pass 79 is interposed in an outlet duct 81 from the vapour compression evaporator 75 whilst the hot pass 80 is interposed in a drain 82 for concentrated brine. The heating pipes 83 of the vapour compression evaporator 75 lie below the level 84 of the salt water contained in the evaporator and steam generated in the evaporator 75 is delivered through an outlet 85 to the inlet 86 of a compressor 87 which is coupled to a turbine 88 by a shaft 89. The outlet from

the compressor passes through the cold pass 90 of a heat-exchanger 91 and thence through a heater 91A and the steam is then supplied to the turbine 88 through an inlet 92. The exhaust of the turbine 93 communicates with the hot pass 94 of the heat-exchanger 91 through a duct 95 and the outlet of the cold pass 94 is arranged to deliver steam through a duct 96 to a de-superheater 97. The de-superheater has an outlet 98 which connects to a branched duct 99, one branch of which 100 communicates with the inlet of the heating pipes 83 of the vapour compression evaporator 75 whilst the other branch 101 communicates with the inlet of the heating pipes 74 of the multi-stage flash evaporator 70. The outlet of the coil 74 communicates with a pump 102 which returns condensed steam to the de-superheater 97 and performs the de-superheating function therein.

In a modification of the plant described with reference to Figure 4, an additional compressor 110 (broken lines) is coupled by a shaft 111 with the compressor 87 and steam is supplied from the vapour compression evaporator 75 through a duct 112, the output of the compressor 110 being delivered through a duct 113 upstream of the de-superheater 97.

In the embodiment of Figure 4 it will be noted that no energy is derived from a boiler and this omission essentially simplifies the plant as a whole. The omission of the boiler plant will result in lower capital cost and because the relatively expensive high-pressure boiler is replaced by a low pressure heater and because a multi-stage high-pressure turbine is replaced by a simple low-pressure turbine.

Despite these advantages, the same flow through the heater and the turbine of the boilerless plant will be higher for a given production of desalinated water than the mass flow of steam from the boiler of the embodiments described, with reference to Figure 3. In practice, it is likely that the heating surface of the low-pressure heater will be of the same order as that of the comparable size of boilered plant. In effect, the heater will include a large number of short passages in parallel through which a large mass flow of relatively low pressure steam is passed whereas a conventional boiler can be considered as a single passage through which passes a relatively small mass flow of water which is converted into very high pressure steam (for example 3000 lb. per sq, in.).

Analysis of the two forms of plant hereinbefore described indicates that the quantity of heat which must be supplied to produce 1 lb. of desalinated water is substantially the same for both forms of plant.

The heat-exchangers used in the embodiments described with reference to Figure 4 could be of the rotary-regenerative type and the low pressure ratio across the two sides of the heat-exchanger (approximately 1.6: 1) would, in practice minimize sealing problems.

In further explanation of the modification illustrated in Figure 4, the compressor 110 serves to reduce the fraction of the plant mass flow passing through the heater circuit, but as can be demonstrated by analysis this has an adverse effect on plant performance in terms of the heat input required per unit mass flow of desalinated water.

As is apparent from Figure 4 feed water heating for the vapour compression evaporator 75 can be effected by means of a separate heat exchanger 77.

The temperature of the steam leaving the heater in Figure 4 can be controlled and held at a predetermined value by the use of a spray de-superheater as in standard steam boiler practice. Such a de-superheater for this purpose has not been illustrated in Figure 4 as it is not a fundamental to the embodiment of this Figure although de-superheater 97, (Figure 4) is shown for use in the removal of superheat from the steam approaching the vapour compression evaporator heater. The heat given up by this steam constitutes the heat input to the multi-stage flash evaporator.

Analysis has shown that on the basis of the thermal input related to the output of desalinated water plant performance does not differ substantially in the embodiment of Figure 4, and that of Figure 3.

The manner of operation of the plant shown in Figure 4 will, it is believed, be apparent from the description given hereinbefore. However, it is necessary to refer to the problem of starting the respective plant and one method is to supply heat to the vapour compression evaporator 75, for example, by passing steam from an outside source through the heating pipes immersed in the brine whilst at the same time rotating the turbo-compressor rotor or the pressure-exchanger rotor and applying heat by any means to the heater of the flash evaporator.

If auxiliary power is required for driving the various pumps, electricity can be generated by coupling the generator to the shaft of the compressor-turbine assembly or alternatively an auxiliary boiler plant can be used to drive a turbo-generator and if this latter alternative is adopted the steam exhaust of the auxiliary turbine is passed into the multi-stage flash evaporator heating surface.

As a further alternative in the case where a boiler is employed in the main plant, the boiler of the auxiliary steam plant could be combined with the main plant heater of the main boiler, hot gases leaving the heater being passed over an auxiliary boiler heating surface before entering the hot pass of the air pre-heater in fossil fuel fired plants or returning to the reactor in nuclear heated plants.

The combined-process plants as hereinbefore described have at least some of the following advantages over processes which com-

prise solely a work-input process for a thermal-input process. These advantages are that the turbine and the shaft power input process still, both of which involve major moving parts, are smaller than would be necessary in a plant in which the whole desalination process took place in either a vapour compression or a freezing process still; that the exhaust from the turbine is not wasted but is utilized as the heat input to a thermal process; and that if only a thermal process were used it would not be practical to make use of the high-pressure steam generated due to the comparatively low upper temperature limit permitted within the heater section of a multi-stage flash or submerged-tube evaporator. This temperature limit is set at least partially by the necessity to avoid scaling and corrosion problems. Currently this limit is approximately 250° F. which implies that heat input steam supplied at pressures greater than approximately 35 lbs/sq. in. absolute cannot be used effectively in such evaporators. A further advantage of a combined-process desalination plant hereinbefore disclosed is that the combination of a work-input and a thermal-input device in one plant results in the elimination of large scale electricity generating equipment, the turbine of the plant being directly coupled to the compressor of either the vapour compression or freezing process still.

A freezing process still is apparatus for separating salt or other soluble minerals from sea water and has been proposed previously for desalination of sea water.

From the foregoing it will be evident that the combination of a vapour compression still and a multi-stage flash evaporator results in a substantial increase in the quantity of desalinated water produced per lb of boiler steam input as compared with a plant incorporating only a multi-stage flash evaporator. This quantity increases as boiler pressure increases. Furthermore, the quantity of heat input to a combined-process plant in accordance with this invention necessary to produce one lb of desalinated water reduces with increasing boiler pressure. Also, a combined-process plant obviates the necessity of producing a possibly unwanted supply of electricity. Thus, problems associated with the independence of fluctuating electricity and water demands in dual-purpose electricity generating and desalinating plants are eliminated without economic penalty by stations and combined-process desalination plants in accordance with this invention, which plant may be used for irrigating large areas of land.

As hereinbefore mentioned, the vapour compression still may be replaced by freezing process still and this should, in principle, result in an overall improvement in performance of the combined-process plant. Further, the multi-stage flash evaporators may be replaced by multi-stage submerged tube evaporators which should, in principle, again result in an improved performance for the desalination plant.

The risk of damage to the compressor of a vapour compression still due to water droplet erosion can be eliminated or at least alleviated by either equipping the inlet with a centrifugal water separator and/or drying or slightly superheating steam entering the compressor by heat transfer from the compressed flow leaving the machine.

WHAT I CLAIM IS:—

1. A desalination plant comprising first apparatus for producing desalinated water the operation of which produces shaft power and second apparatus for producing desalinated water which depends essentially for operation on a thermal input derived from the exhaust of the first apparatus, said first and said second apparatus having intakes for saline water arranged in parallel.

2. A desalination plant comprising a first apparatus operable with high-pressure steam to produce an output of desalinated water and low-pressure steam and a second apparatus operable by the exhaust of the first apparatus to produce an output of desalinated water, said first and said second apparatus having saline water intakes arranged in parallel.

3. A plant according to claim 1, wherein the first apparatus comprises a vapour compression still.

4. A plant according to claim 1, wherein the first apparatus comprises a freezing process still.

5. A plant according to claim 3 or 4, wherein the second apparatus comprises a multi-stage flash evaporator.

6. A plant according to claim 3 or 4, wherein the second apparatus comprises a submerged tube evaporator.

7. A desalination plant comprising a vapour compression evaporator, a turbine-driven compressor arranged to provide heating fluid to the vapour compression evaporator and a multi-stage flash evaporator connected to receive exhaust steam from the turbine, respective inlets to the vapour compression evaporator and to the multi-stage flash evaporator being arranged for parallel connection with respect to a saline water source.

8. A desalination plant comprising a vapour compression evaporator having an outlet connected to a compressor, a heat-exchanger the cold pass of which receives heat from the hot pass thereof, a heater downstream of the cold pass and communicating at its outlet end with the inlet of a turbine, an outlet of the turbine connected to the hot pass of the said heat-exchanger, a de-superheater connected to receive the output of the said hot pass of the heat-exchanger having a cold pass through a multi-stage flash evaporator and connected to receive steam from the de-superheater, said vapour compression evaporator being connected to deliver steam to the inlet of the said

compressor and having heating means therein connected to receive steam from the de-superheater, and a further heat-exchanger having a hot pass for brine delivered from the vapour compression evaporator and a second hot pass connected to receive desalinated water from the vapour compression evaporator, said further heat-exchanger havin ga cold pass through which salt water can be delivered to the vapour compression evaporator after taking up heat in said further heat-exchanger, said multi-stage flash evaporator having an inlet for salt water arranged in parallel with an inlet to said cold pass of the further heat-exchanger.

9. A desalination plant according to claim 1, wherein the shaft power is derived from a turbine-compressor assembly and the thermal desalination apparatus takes the form of a multi-stage flash evaporator connected to receive exhaust steam from the turbine.

10. A plant according to claim 9 wherein the shaft-power-operated apparatus includes a vapour compression evaporator connected to receive the output from the compressor and arranged to deliver the desalinated water through a feed heater upstream of the vapour compression evaporator.

11. Apparatus according to claim 10 further comprising a heat-exchanger in which heat is exchanged between concentrated brine rejected from the vapour compression evaporator and the inlet of fresh salt water.

12. A plant according to claim 10 comprising a further heat-exchanger connected in ducting leading to the inlet of the compressor and constituting a cold pass thereof, the hot pass of the heat-exchanger being connected to ducting downstream of the outlet of the compressor and communicating with the heating pipes of the vapour compression evaporator, said further heat-exchanger serving to dry the steam before entry to the compressor.

13. A desalination plant according to claim 1, comprising a de-superheater interposed between a thermal output of the shaft power apparatus and the thermally-operated apparatus.

14. A desalination plant substantially as hereinbefore described with reference to the accompanying drawings.

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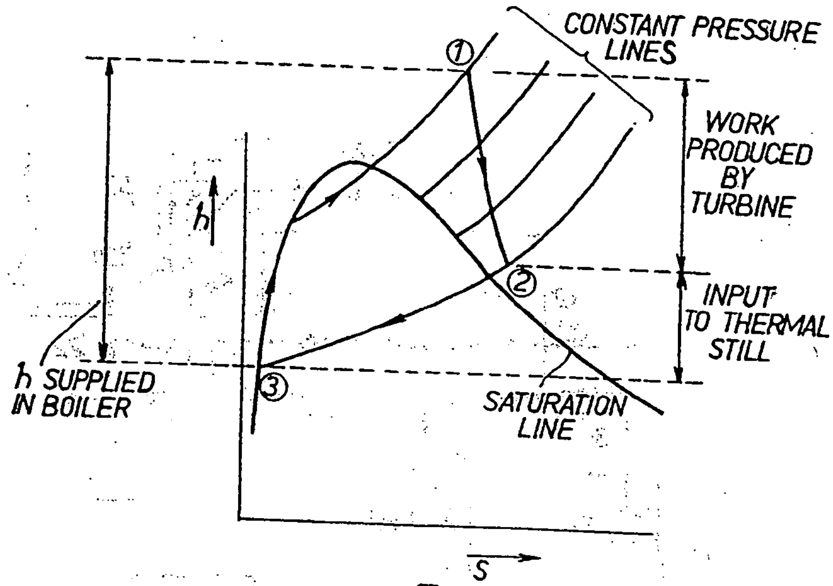
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FIG. 1.

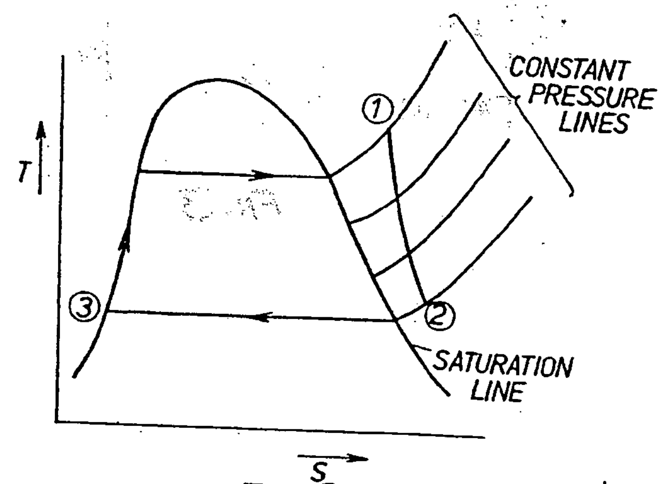
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FIG. 2.

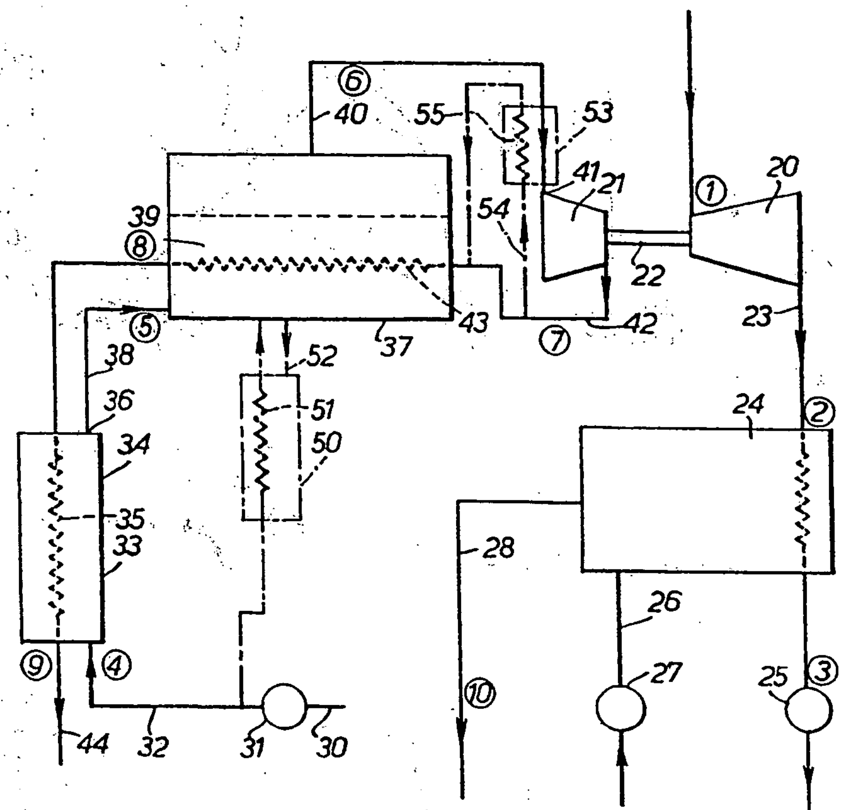
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FIG.3.

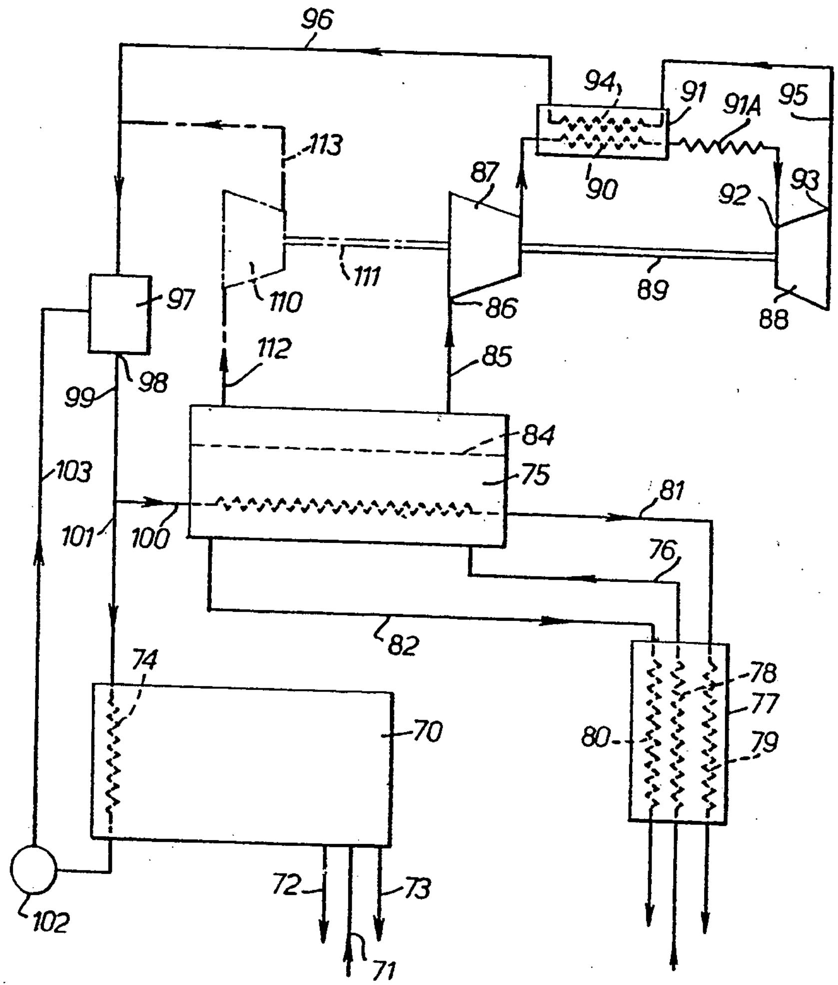
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FIG. 4.